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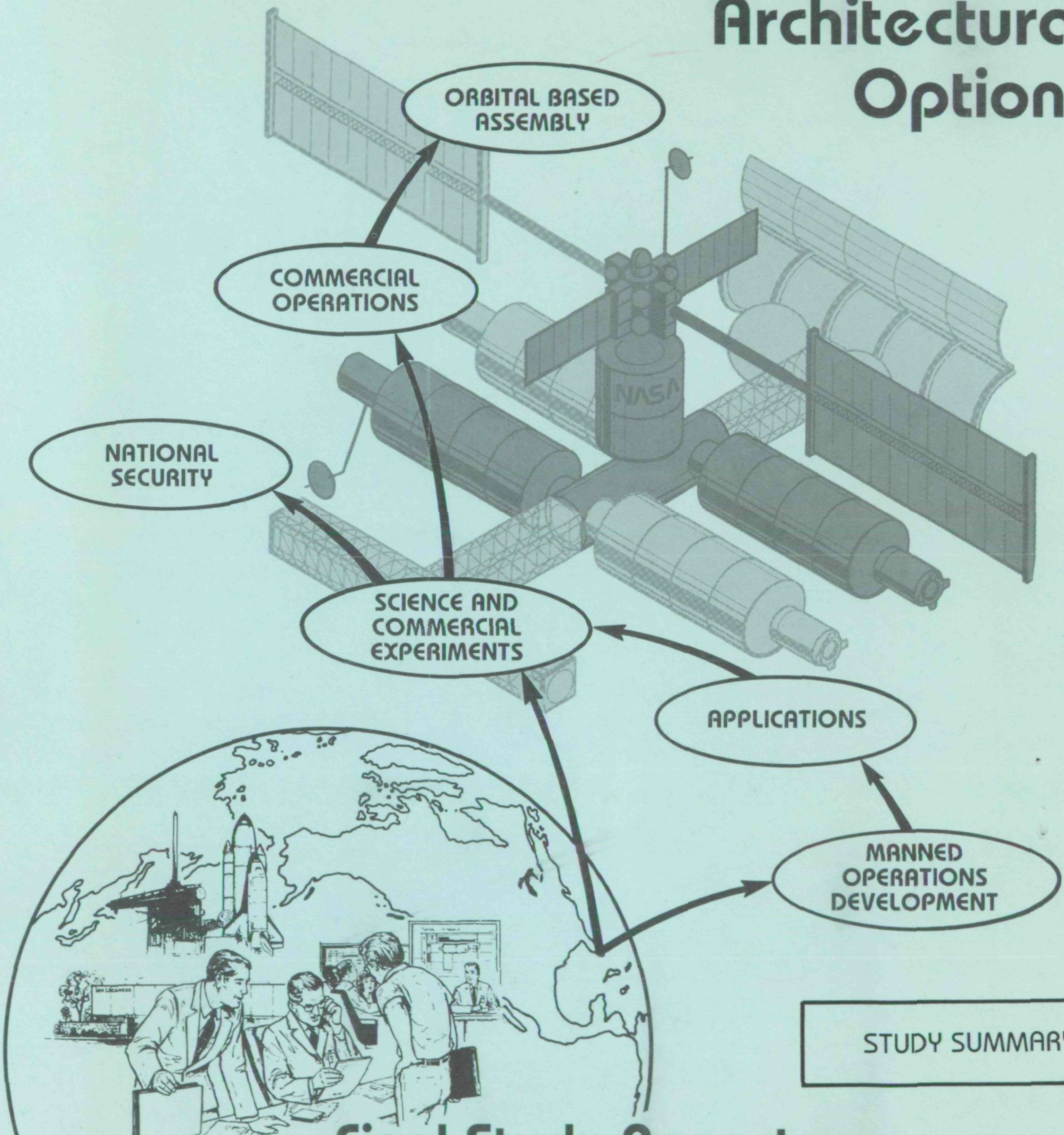
NASA Space Station Needs, Attributes and Architectural Options



STUDY SUMMARY

Final Study Report

Lockheed Missiles & Space Company, Inc.

LMSC-D889718
22 APRIL 1983

NASA Space Station Needs, Attributes, and Architectural Options

FINAL STUDY REPORT

CONTRACT NASW-3684

22 APRIL 1983

STUDY SUMMARY

Prepared For NASA Headquarters
Washington, D.C.

Prepared By Lockheed Missiles & Space Company, Inc.
Sunnyvale, California 94086

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ABSTRACT

This report presents the results of a study to determine space station needs, attributes, and architectural options that affect the future implementation and design of a USA Space Station system.

An understanding of space station needs was developed through personal contacts with potential users. Repeated contacts were necessary to develop sufficient information to define requirements. Requirements were established for several mission scenarios, a number of which could benefit from the continuous presence of man in space. One mission with considerable interest and support, and a compelling need for the continuous presence of man in space, is the National Orbiting Command Post.

Requirements for candidate missions were used to define functional attributes of a space station. Station elements that perform these functions form the basic station architecture. Alternative ways to accomplish these functions were defined and configuration concepts were developed and evaluated. A reference space station configuration was selected and an evolutionary plan was developed that increases station capability from an initial station in 1990 to an advanced configuration station in 1996.

Configuration analyses were carried to the point that budgetary cost estimates of alternate approaches could be made. Emphasis was placed on differential costs for station support elements and benefits that accrue through use of the station.

Areas requiring further study and technologies needing further development were defined.

FOREWORD

The Lockheed Missile & Space Company, Inc. (LMSC), using inputs and efforts from our subcontractors, consultants, and companies providing information under data exhange agreements, has completed all requirements of the Space Station Needs, Attributes, and Architectural Options, Contract NASW-3684 for NASA Headquarters, Space Station Task Force. This report presents a summary of the 8-month study that consisted of the following tasks:

- TASK 1 - MISSION REQUIREMENTS. User alignment including contacts, data compilation, evaluation, and mission requirements definition are covered under this task. The objective, as stated in the NASA RFP (W 10-28647/HWC-2) is to identify specific users, with their address and telephone numbers, who can substantiate the user defined requirements identified by the contractor.

- TASK 2 - MISSION IMPLEMENTATION CONCEPTS. Alternative concepts, architectural options, performance capability, space station evolutionary capability, and space operations are discussed under this task. Detailed design are to be avoided, per NASA direction.

- TASK 3 - COST AND PROGRAMMATIC ANALYSIS. Socio-economic benefits, cost effectiveness, and cost and schedule analysis for an evolutionary space station are presented under this task.

The subcontractors were:

- Arthur D. Little, Inc.
- ECON Corporation
- Vought

Data Exchange Agreements with:

- Dornier, Germany
- General Technology Systems, England
- Hamilton Standard, U.S.A.
- IBM, U.S.A.
- MBB/ERNO, Germany
- SPAR, Canada

These agreements provided at no cost to this contract.

Consultants:

- W.C. Hayes, Jr.
  William C. Hayes Assoc., Inc.
- W.M. Hawkins
  Lockheed Corporation
- Prof. H. Ashley
  Stanford University
- J. Carroll
  UC San Diego
- R. Wolfe
  Richard G. Wolfe Assoc., Inc.

This final report includes a summary of the study approach and results. Included as attachments to the final report are the following:

1. Attachment 1, Study Presentation Material
   - Volume I - Executive Summary
   - Volume II - US National Security (classified)
   - Volume III - Task 1, Mission Requirements
   - Volume IV - Task 2, Mission Implementation Concepts and Task 3, Cost and Programmatic Analysis
2. Attachment 2, Supporting Data and Analysis Reports
   - Volume I
     Reference Space Station Evolution
     Contact List
     Data Base
     Scenarios
     Commercial Report
     Vought Corporation (TMS)
     Life Sciences and Life Support Development
     Experiments on a Space Station
     SPAR Report
     Hamilton Standard
   - Volume II
     Architectural Impact Analysis
     Configuration Concepts Evaluation
     CADAM Drawing File
     EVA Technology Needs
     Manned System Technology Requirements

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Section 1
INTRODUCTION AND SUMMARY

The objective of the Space Station Needs, Attributes and Architectural Options (SSNAAO) study was to develop a potential user base, mission requirements, architectural concepts, and costing for a space station system.

Figure 1-1 shows a configuration concept of a space station developed from the reference station concept that resulted from the study.

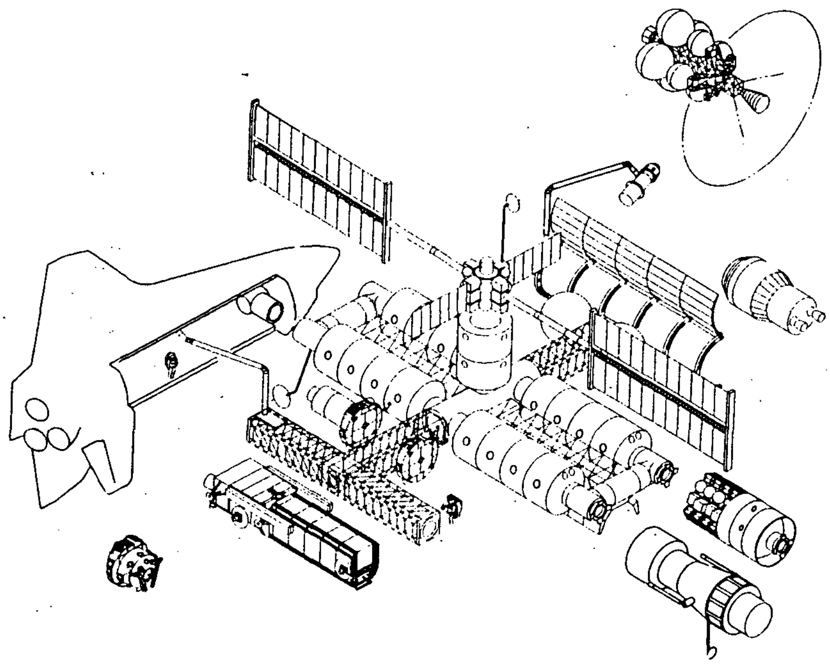

Fig. 1-1 Space Station Advanced Concept

INTRODUCTION

The space station study effort was performed from 23 August 1982 through 22 April 1983 under the National Aeronautical and Space Administration Headquarters, Contract NASW-3684. The contract consisted of NASA and DoD sections. The three tasks performed were:

<u>Task 1: Mission Requirements</u>. A user alignment plan for five mission categories: Science, Commercial, U.S. National Security, Applications, and Space Operations was developed and executed. Technology missions were also defined. The major issues were to set up a method for conducting potential user contacts and to develop a data base from the resulting requirements.

This task covers the evaluation of the user data base and data categorization, and major potential benefits in correlation with the current STS and space station.

Task 2: Mission Implementation Concepts. Alternative system concepts, development of architectural options, evolutionary space station performance capability, and cost effectiveness analysis were performed under this task. Architectural concepts with minimum emphasis on physical design aspects, but with emphasis on functional aspects were also developed.

Task 3: Cost and Programmatic Analysis. This task provided parametric costs for STS and space station missions, schedule variation cost differentials, benefits, new capability demands, cost, schedule, and funding for an evolutionary space station.

DoD Task. Scenarios were developed for possible military applications, and cooperative efforts for NASA and DoD space station options.

1.2 STUDY SUMMARY

Space station mission requirements, alternatives, options, evolutionary growth, and cost were based on contacts with potential users, engineering judgment based on past experience, inputs from consultants, and other studies. From a technical point of view a space station could be placed in a low earth orbit at the end of this decade. The problem confronting us is the question of need.

The users in the areas of science and applications have expressed a modest level of interest in the use of a manned space station. Their primary concern is that the space station will erode funding available for science missions, particularly in the area of physical sciences. Specialists in life sciences are strongly enthusiastic about a space station because it provides the only opportunity for long duration life science experiments in zero-g. At present the science community is not fully aware of the synergistic cost benefits of a manned station versus an unmanned space platform or free-flying satellites. Though science missions will make effective use of a space station, these missions will not justify the development of a station, except as part of a national commitment to explore space.

There is a strong interest in the commercial community on the potential uses of space. The specific uses of space for commercial activities are ill-defined, however, and data are not available to encourage investment in speculative space ventures at this time. The only demonstrated benefit of space processing is the McDonald Douglas/Johnson and Johnson Electrophoresis. The commercially successful field of space-based communications will continue to be a viable commercial enterprise, but the role of the space station appears to be confined to a construction base for large geo-stationery platforms; the need for such large systems is controversial at this time. A number of contacts have been developed by Lockheed, A. D. Little, and other contractors. Throughout these contact power requirements

in specific were stressed, however, no hard values could be extracted from the users. With an eye for future development, and with the experience gained through past industrial growth cycles, it is felt that the space station should be designed as a power rich facility. A power need of about 50 kW should be a solar system however, with power requirements in the 250 - 500 kW range a nuclear power reactor would be the choice. NASA has an excellent opportunity to work with this interested and motivated commercial community to develop commercial missions for the future. However, NASA must fund the basic research needed to define commercial opportunities. Such activity may provide a realistic base for supporting the space station at a future date.

The U. S. National Security users indicate strong interest in a space station for research and development activities but, just as in the case of science missions, the research and development cannot justify the construction of a station for that purpose alone. The space-based servicing of National Security satellites can be a very important role for the space station. Cost trades have shown space-based servicing to be more efficient than shuttle-based servicing under certain conditions (satellites must be near the same inclination as the station, and servicing must be performed at nodal coincidence). The constraints of orbit mechanics must be clearly understood to properly define space station servicing missions.

The use of the space station for operational missions in the National Security area is discussed in the classified section (Attachment 1, Volume 2) of this report. No consensus has been reached within DoD on the appropriate role of a manned space station. However, Lockheed has been effective in stimulating substantial interest in developing the definition of a National Security operational requirement for a manned space station. This mission may, in fact, provide the key to generating broad base support to start the space station.

The space operations support from the space station may well be the most important single category of activity. Cost benefit analyses show a substantial advantage for space operations support to users in all of the previous categories (Science, Applications, Commercial and National Security) for a space-based servicing system. As noted, however, the constraints of orbit mechanics must be considered in planning space station missions. Many satellite servicing activities will be better performed by the space shuttle and this must be properly accounted for in space station planning. The space station also provides a base for a shuttle crew rescue mission as an alternate to a ground based rescue. This significant enhancement of the STS system safety is a strong argument in favor of a space station.

An immediate and pressing need for a space station was not identified during the course of this study. However, military requirements may dictate a need for a United States permanently manned presence in space and may become the overall drivers for a space station. Parallel civilian space work would then be possible during at least the early stages of an evolutionary space station.

1.3 STUDY TEAM

Bearing in mind the importance of this study in the furthering of space exploitation, the best qualified team was selected. The team consisted of LMSC, subcontracters, companies with whom we developed data exchange agreements, consultants, the Technology Coordinating Committee, and a Senior Advisory Council (Fig. 1.2).

LMSC was responsible for the conduct of the study and NASA interfacing.

<u>Subcontractors</u>. A number of subcontractors were included in the team, they are:

- A.D. Little, Inc., responsible for performing commercial seminars
- ECON Corporation, responsible for benefit, economic, and cost analysis
- Vought, responsible for TMS

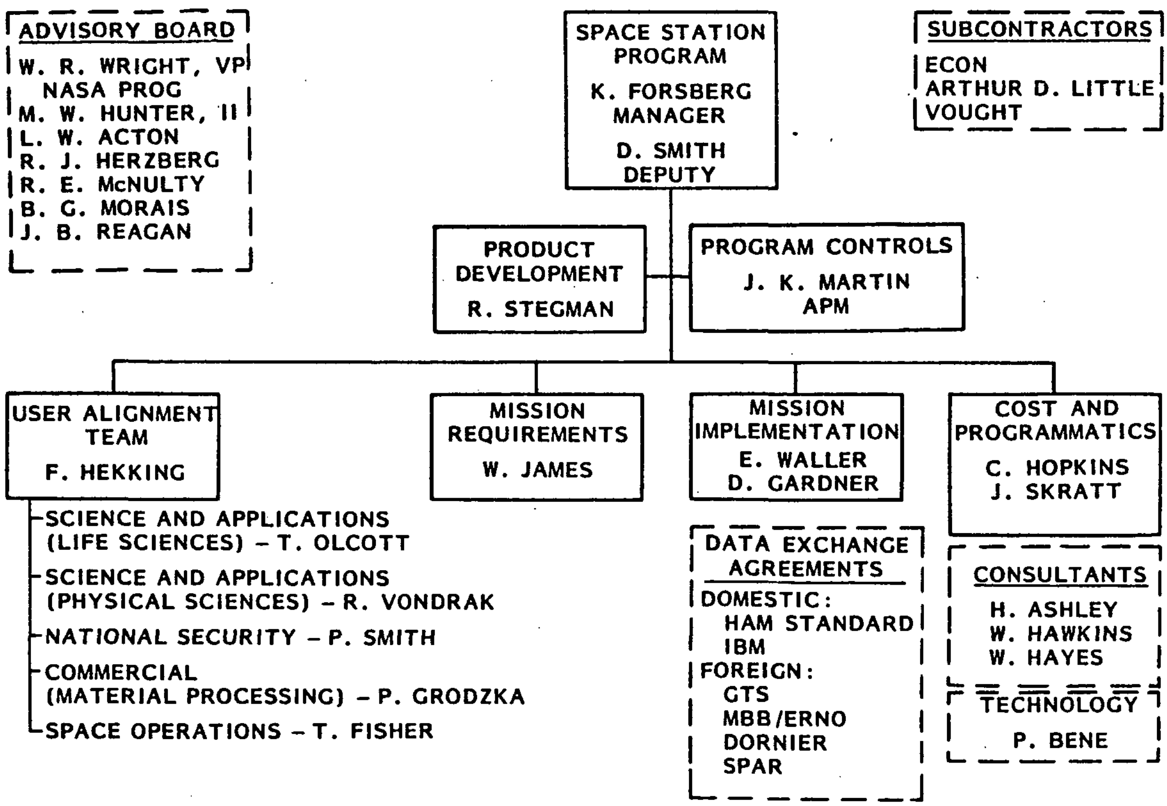

Fig. 1-2 Study Team

Agreements were reached with a number of domestic and foreign companies:

- Hamilton Standard - USA, presented information on life support systems
- IBM - USA, presented data management information
- SPAR - Canada, presented RMS design information
- Dornier - Germany, presented information on life support systems. They have been very cooperative in supplying information. They are under ESA contract to perform space station related studies.
- MBB/ERNO - Germany, also has agreements with the other seven contractors. We have had contacts with them on the general subject of space station support. They are under contract to ESA.
- GTS - England, is under contract to ESA with the specific task of correlating the European space station effort with the American effort. They have an exclusive agreement with Lockheed. We have had a number of contacts with them both in England and here in the U.S.

Consultants were chosen for their backgrounds in space-related business and space stations.

- W.C. Hayes, Jr.

  William C. Hayes Associates, Inc. Mr. Hayes brought to the study his extensive knowledge of NASA shuttle and space station systems. This support has proven invaluable in many instances.

- W.M. Hawkins
  Lockheed Corp.

  Mr. Hawkins has shared freely of his experience as a member of the NASA Advisory Council. He has kept the study focused on the more important NASA issues.

- Professor Holt Ashley
  Stanford University

  Professor Ashley has given us many suggestions on the priority of space station issues and the direction that the study should take.

- J. Carroll
  University of California San Diego

  Mr. Joe Carroll provided consulting services to Lockheed on the satellite tethering concept as applied to the space station.

His expertise on tethering and utilization of the shuttle external tanks proved to be valuable support to the Lockheed analysis.

- R. Wolfe
  Richard G. Wolfe Assoc., Inc.

  Mr. Dick Wolfe contributed to the development and analysis of National Security mission scenarios.

The Technology Coordinating Committee, formed before this space station study commenced, has kept in contact with the NASA technology requirements and direction of effort. This effort was helpful in both the area of the study and in the area of LMSC Independent Development program planning.

The Senior Advisory Council was convened seven times during this study period. Members of the council have given us important pointers on the method and means to clarify presentations, and have helped identify the more important space station system aspects that required more emphasis in the study.

1.4 SCHEDULE

Figure 1-3 presents an overview of the space station study schedule. Total period of performance was eight months, 23 August 1982 through 23 April 1983.

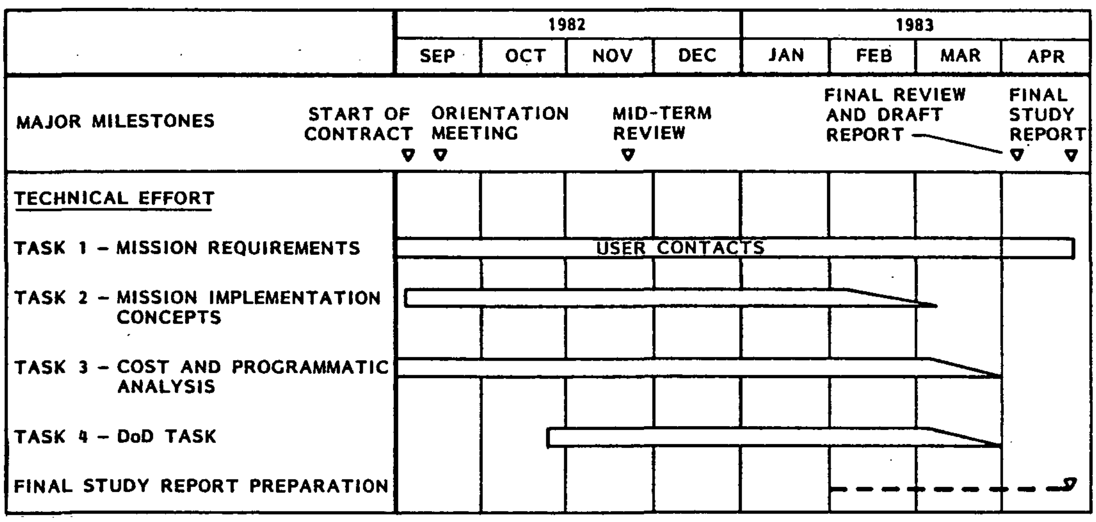

Fig. 1-3 Study Schedule

Task 1 (Mission Requirements) (about 65 percent of contract effort) was performed throughout the study period. This task included the potential user contacts effort. These contacts were one of the most important parts of the study and were therefore strongly emphasized. This effort resulted in mission scenarios, mission requirements, and space station evolutionary growth requirements.

The midterm review was presented to NASA Headquarters on 15 November 1982, with audio interfaces to MSFL, JSC, and JPL. LMSC representatives presented the review view foils at each site simultaneously.

Task 2 (Mission Implementation Concepts) (about 25 percent of contract effort) was performed from October 1982 through March 1983. This effort resulted in alternative concepts and options some of which were used for costing evaluation. Technology issues that needed highlighting were reviewed and listed. Space Station evolutionary growth architectural concepts were documented. Although "design" was not really wanted here, some "design" work had to be performed for costing purposes. Subsystems were analyzed only to the extent required to support cost analyses. A multitude of trade studies has been performed on many of the issues still confronting us. Areas with possible problem impacts are being studied in a number of IR&D programs at Lockheed.

Task 3 (Cost and Programmatic Analysis) (about 10 percent of contract effort) was performed from December 1982 through March 1983. Of course appreciable preparatory effort for this task has been expended from the beginning of this study. Socio-economic benefits, spin-offs in technology, cost estimates, incremental capability, and schedule variation costs have been analyzed.

Task 4 (DoD) was performed in parallel with tasks 1,2, and 3, from August 1982 through March 1983. The unclassified effort performed under the National Security heading is presented here.

Most of the DoD effort is reported in a separate classified volume.

Section 2
STUDY OBJECTIVES AND GUIDELINES

The objectives of this study were to define user requirements and develop support for an American space station system to be placed in a low earth orbit.

2.1 STUDY OBJECTIVES

The objective here was to attract and cultivate potential users, national and international for the space station in the five categories previously mentioned. From these inputs mission requirements on a time-phased basis were developed.

Architectural concepts were developed from the mission requirements (Task 1). Space station evolutionary concepts were used to obtain costs for the time period of the evolution. A number of alternatives and options were analyzed.

Cost and programmatic analysis had as an objective the costing of an evolutionary space station system in line with the economic capability of the USA, and NASA funding capability at such time as needed. A number of benefits analyses were performed assuming the existence of a space station system.

2.2 STUDY GUIDELINES

Specific NASA study direction was kept to a minimum throughout the study. This was done to allow an unencumbered flow of ideas without cross fertilization with the other seven contractors. In January 1983 a letter from R. F. Freitag entitled, "Comments/Redirection of Activities for Studies of Space Station Needs, Attributes and Architectural Options," was received and incorporated in the study activities.

One study guideline that stands out was the statement that "detailed designs are not desired." Architectural concepts were not to be construed as being physical designs, but rather requirement concepts. However, for costing purposes, designs were developed to a level of detail required for the cost analyses. Without some of these details, such as mass and power, cost analyses would not have been credible.

Section 3
SPACE STATION STUDY RESULTS

3.1 MISSION REQUIREMENTS (Task 1)

The approach taken to define space station requirements was to use existing data where available and to acquire new, or verify existing, requirements through personal contacts with potential users. The existing data base provided near adequate coverage of requirements in the science area, particularly physical sciences. A substantial number of personal contacts were made in the life sciences and applications areas to enhance this data base. Definition of requirements was found to be very limited in the area of commercial applications and therefore a considerable number of personal contacts were initiated and two seminars were held under joint sponsorship of Lockheed and the Arthur D. Little Company. Both the contacts and seminars were beneficial in developing commercial user interest, but neither resulted in a significant number of hard requirements.

A significant number of contacts were developed in the National Security area. The effort was focused on development of an operational mission since this seemed to be the most important step in finding a compelling reason to proceed with construction of a manned space station. As a result of repeated visits with the major commands within the Air Force, as well as discussions with personnel within the Army and Navy, an operational scenario was defined and has been received with broad interest. The area of space operations was also discussed with potential users in all categories. For appropriate missions the space-based support of space operations is more cost effective than shuttle based support. This category of activity may also represent a compelling reason to proceed with the space station. The user requirements, however, are ill-defined and further work is required to provide more definitive cost-benefit data.

Lack of spontaneous user response in defining requirements in detail led to the decision to develop a few (i.e., 15 to 20) specific mission scenarios (Fig. 3-1). The scenarios were used in repeated user contacts with the intent of obtaining endorsement of some of the scenarios for which requirements could then be defined. This technique, though it did not result in a large number of solidly endorsed missions, proved successful in establishing meaningful dialog with users and led to definition of a substantial number of mission requirements.

Lockheed used a computerized system (ARTS) to manage the the data base. A complete print out of the data base is included in Attachment 2, Volume I. Mission scenario data and requirements were also submitted to the NASA LaRC in the format requested.

3.1.1 USER ALIGNMENT PLAN

Lockheed embarked on a user alignment plan which focused on personal contact (with repeat visits) to establish rapport with users and to develop a working relationship that enhanced the cooperative effort needed to define requirements.

Mission scenarios were used to focus on specifics that could lead to requirements definition. The scenarios, shown in Fig. 3-1 are also listed and discussed in Attachment 2, Volume I.

A computerized list of contacts was maintained throughout the study. The list, continuously updated, indicate personnel, agencies and dates of contacts. The total number of contacts made was 323 which included 117 in the Science and Applications area, 98 in Commercial, 65 in National Security and 43 International. The list is provided in Attachment 2, Volume I.

SOURCE	MISSION SCENARIO	EARLIEST USE
USER SURVEY		
• SCIENCES	LIFE SCIENCE HUMAN RESEARCH LAB	1990
	LIFE SCIENCE NON-HUMAN RESEARCH LAB	1990
	CELESTIAL OBSERVATORY	1990
	SPACE ENVIRONMENT FACILITY	1990
• APPLICATIONS	EARTH OBSERVATION FACILITY	1990
	GLOBAL HABITABILITY OBSERVATION LABORATORY	1990
	METEORLOGICAL FACILITY	1990
• COMMERCIAL	MATERIAL PROCESSING RESEARCH LAB	1990
	MATERIAL PROCESSING FACILITIES	+ 5 YRS
• U.S. NATIONAL SECURITY	SPACE OBSERVATION DEVELOPMENT LABORATORY	1990
	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB	1990
	ORBITING NATIONAL COMMAND POST - NASA IMPACT	1990
	- OPERATIONAL	1998
	SPACE OBJECTS IDENTIFICATION SYSTEM	1995
• SPACE OPERATIONS	ON ORBIT SATELLITE SERVICING-LEO (ITSS, SBR, GPS)	1993
	LARGE STRUCTURES ASSEMBLY (SBR)	1992
	ASTRONOMY PLATFORM SUPPORT	1990
	SPACE TELESCOPE MAINTENANCE	1990
	PROMPT SATELLITE REPLACEMENT	1993
	SHUTTLE CREW RESCUE VEHICLE	1990
	GEO SATELLITE RESUPPLY	1990

Fig. 3-1 Mission Scenarios

3.1.1.1 SCIENCE AND APPLICATIONS

Science contacts in both the Life Sciences and Physical Sciences areas were primarily with the NASA centers including JPL and with universities. The scenarios presented for discussion are:

Physical Sciences

1. Celestial Observatory
2. Space Environment Facility

Life Sciences

1. Life Sciences Human Research Lab
2. Life Sciences Non Human Research Lab

The Physical Sciences community though concurring with the validity of the scenarios presented could not justify the need for man in the loop in space to perform these missions. It is clear, however, that given a space station, considerable benefit can be derived from operating physical science missions with a man in the loop for purposes of calibration, data management and taking advantage of targets of opportunities. The Life Sciences, on the other hand, inherently involves man in the loop in space in that he is the subject of research. The Life Sciences community was not able to define a compelling requirement for man in space other than to meet the self fulfilling need for human research and related operations.

The issue of whether or not there is a requirement for artificial gravity on the space station cannot be resolved at this time. It is not envisioned that the station will be designed for providing a gravity field, but research may show a need for artificial gravity in the future, particularly for advanced stations that may be manned by the same personnel for long durations such as six months or a year or more.

3.1.1.2 COMMERCIAL

Commercial scenarios focused on materials processing, with first a scenario for a research facility then a production facility. Other scenarios could, and perhaps should, be considered, particularly in the area of telecommunications, the one area of space commercialization that has already became profitable.

As the commercial sector was approached, particularly in the area of materials processing, it became evident that these potential space station users were not familiar with opportunities that space operations would provide. For this reason it became evident that education of this segment is essential. The two Space Commercialization Seminars conducted by Lockheed and

Arthur D. Little were designed to initiate this education process and develop rapport with users so that more detailed technical interchanges could be initiated on a follow-up basis. Considerable interest was expressed and it is now important for NASA to provide some mechanism for proceeding with commercial user contacts.

Commercial use of the space station poses a number of challenges. The first of these is legal and regulatory issues which includes ownership of extraterrestrial resources, protection of proprietary rights and anti-trust conflicts. Interfaces with the federal government is a second area which includes applicable regulations, liability, communications accountability and possible interference with operations. A very significant challenge is the potential conflict with DoD activities and concern by commercial interests that they may be preempted by the military. A solution to this problem is separate space stations which will probably happen eventually. The commercial sector expects to see a return an investment in five years which for space systems is rather short.

NASA/industry joint ventures need to be considered and worked out, and the issue of government control of access to space must be understood.

Commercial-based contacts have led to the conclusion that a great deal of interest in space commercialization exists, but more education regarding possibilities is necessary. It is apparent NASA has an opportunity to stimulate commercial projects through initiation of a research program which will define benefits of space commercialization. Such a program should include experiments which can be initially performed on the shuttle before progressing to the space station.

3.1.1.3 NATIONAL SECURITY

Based on the premise that a space station will not create new military missions, but rather will provide a new beneficial means for accomplishing existing missions, it seemed appropriate to review existing systems to determine if the presence of a space station would influence the ways in which these missions are performed. These missions are shown in Fig. 3-2.

The space station could provide a base for data reduction and analysis of information from remote satellites prior to transmitting the information to the ground. In this

SYSTEMS	AUGMENT PERFORMANCE	RDT&E	SATELLITE MUST BE SPECIFICALLY DESIGNED FOR THESE OPERATIONS				OBSERVE	DEPLOY/ RECONSTITUTE	RETRIEVE
			REPAIR	ASSEMBLE/ RESUPPLY	CHANGE-OUT	RECON-FIGURE			
DSP	X	X							
AWS	X	X							
GPS	X		X		X			X	
IONDS	X	X						X	
DMSP	X		X	X	X	X	X		
GEODSS	X	X							
DS^3	X	X	X	X	X	X	X		X
NAVSPASUR	X	X							
HOE ADVANCE SENSOR	X	X	X	X	X	X	X	X	X
PAVE PAWS	X	X							
SPASER		X	X	X	X	X	X		X
AFSATCOM	X							X	
SPACE CRUISER	X	X	X	X	X	X	X	X	X
SCF/CSOC	X								
SCS	X	X							
SHUTTLE	X		X	X	X	X	X	X	X
ELVs	X								
ADVANCED MILITARY SPACECRAFT		X	X	X	X	X	X		X

Fig. 3-2 Potential Military Applications of the Space Station

role it is possible that the station could augment the performance of existing systems. There is substantial diversity of opinion on whether or not this is a valid role for a manned system, however, and there is no identified support at this time to propose this role, as a primary operational requirement for a manned space station. There is considerable interest in evaluating the potential capability for man's involvement in this role but strictly as a research and development activity.

There is substantial agreement that the manned space station would provide an excellent research and developmemt platform for check out and evaluation of new components as well as satellite systems. In that sense the RDT&E column in Fig. 3-3 is intended to show the benefit in using the space-based platform for development of the next generation of an existing satellite system.

Satellite servicing activities, which comprise the seven remaining columns (Fig. 3-3) are clearly an accepted and signficant function of the space station. It must be emphasized that satellites must be specifically designed for the repair, assembly, resupply, change out, and reconfiguration activities. Existing systems, for the most part, are not designed for space-based support. By the early 1990s, however, new generations of satellites will be launched and these should be designed for space-based satellite servicing.

Considerable emphasis was placed on National Security contacts and specific mission scenarios which probably have more near term support than any others. The National Security scenarios used are:

1. Space Observation Development Laboratory
2. Oceanographic Observatory Development Laboratory
3. Orbiting National Command Post
4. Space Objects Identification System

The Navy has expressed great interest in and has pointed out the value of having a man in space during the developmental phase of sensors (Scenario 2 above). This appears to be a very strong reason for man's presence in space even though such sensor systems could likely be operated quite satisfactorily on an unmanned platform after completion of development.

Considerable effort has been expended in the definition of an Orbiting National Command Post (Scenario 3 above) and communications with Air Force agencies. Details of this scenario are available in Attachment 1, Volume II (classified).

Contacts were made with all military services. Both the Air Force and the Navy have expressed interest in at least one of the scenarios presented. Potential space station applications were reviewed with the US Army and though interested in some possibilities, the use of man in space on a space station to perform mission tasks specific to Army needs was considered to be unnecessary and probably impractical within the time frame proposed for early station implementation.

3.1.1.4 SPACE OPERATIONS

Space-based operational activities will support users from the science, applications, national security, commercial and technology mission areas. For this reason users in all categories become "operations users". The distinction between various categories of space operations is based on the type of activity to be performed, rather than the specific end user. Of more importance is the location at which space operations are performed (e.g., near the space station, or far from it). The type of operations required are also categorized into those on-board operations which include support of the station itself and support of on board experiments, assembly, docking, transfer, etc. Remote operations cover all system elements not attached to the station. The location of satellites being supported in Low Earth Orbit (LEO) places very real constraints on accessibility, revisit frequency and type of servicing operations because of energy requirements.

Potential operational missions such as satellite maintenance, assembly of large space structures, servicing of free-flying experiment platforms, and storage of dormant satellites in the vicinity of the space station have been discussed with user contacts in all of the mission areas. The mission requirements for space operations to be supported by the space station have been defined through analysis of the user mission requirements. A series of scenarios were developed which define the key characteristics of each of these mission categories. The scenarios are:

1. Space-based radar (ITSS) maintenance
2. Large structures assembly (large antenna for space radar)
3. Astronomy platform support
4. Space Telescope maintenance
5. Prompt satellite replacement
6. Shuttle crew rescue vehicle
7. GEO satellite resupply

The operations can be defined in terms of the following categories:

ONBOARD

1. Hard docked, captive free flyer, and tethered satellites

REMOTE

2. Support of satellites in local station vicinity
3. Support of satellites in nearby inclinations at nodal coincidence
4. Universal support of LEO satellites
5. Universal support of GEO satellites

Remote categories two through five involve servicing at varying distances from the station. Satellite location control relative to the station (category 2) can be accomplished by techniques such as use of satellite drag characteristics and drag makeup thrusters to orbit the station (see Fig. 3-4) or by placing the satellite in elliptical orbit with the same period as the station has in its circular orbit. Delta velocity requirements for reaching these satellites are quite low ($<$160 fps) and are easily achievable with a propulsive stage such as the TMS. TMS performance capabilities are included in Attachment 2, Volume I.

Those satellites more distant from the station but that are near the same inclination are easily accessible with an OTV when nodal coincidence exists. At times other than at nodal coincidence ΔV and corresponding propellant requirements become quite large. Fig. 3-5 illustrates the envelope of satellite accessability at any given time. The envelope is a function of OTV capability.

The operational capability of an orbit transfer vehicle (OTV) is a function of its total impulse (controlled by the propellant and engine configuration), the vehicle inert weight, the presence or absence of an aerobraking system, the payload to be carried, and whether the payload is to be transferred in a placement mission, a retrieval mission, or a combination of both. Given these characteristics, one can compute the volume of space which can be reached by the specific orbit transfer vehicle. All satellites within that volume could be supported by the space station with a space based OTV. This assumes, of course, that the satellite has been designed to be serviced or otherwise supported by the space station.

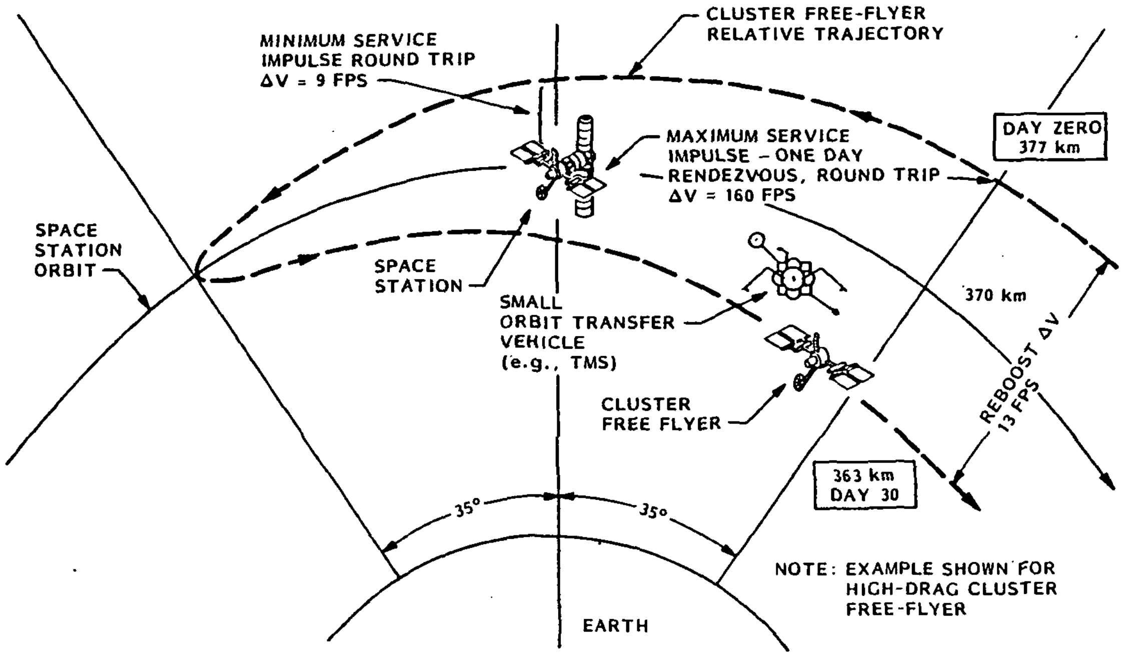

Fig. 3-4 Space Station with High-Drag Free-Flyer

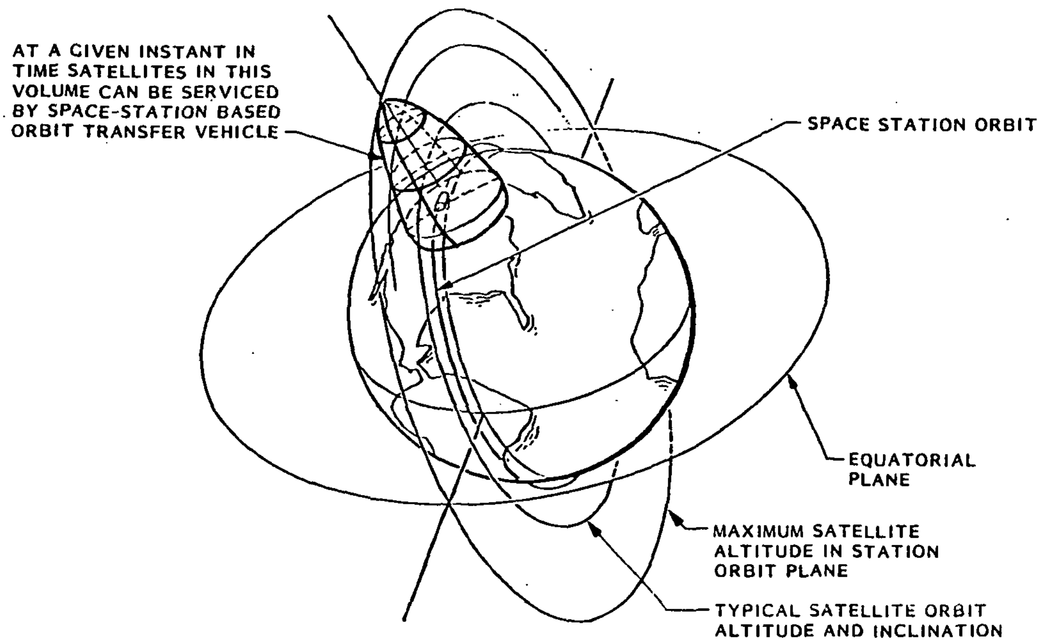

Fig. 3-5 Space-Based Satellite Servicing Envelope at Given Time

The specific satellites that are captured within the service volume of the OTV will change over time. Understanding of this change is essential in order to define the capabilities and usefulness of space based satellite servicing.

Orbit Mechanics Analysis of OTV requirements to support universal support of LEO satellites has shown the need for performance gains achievable through use of an aerobraking system on the OTV. Results of extensive analyses of servicing capabilities and limitations cover OTV propellant requirements, the effect of servicing out non-optimum times and the influence of space station inclination are reported in detail in Attachment 1, Volume IV. Conclusions drawn from these analyses include:

a) The space station provides a powerful capability for space based operations.

b) Understanding of orbital mechanics constraints is essential for proper mission planning.

c) Station is better than shuttle for supporting scheduled servicing, maintenance, and resupply of:
   - Payloads and satellites in station tracking orbits
   - Satellites in nearby inclinations at nodal coincidence, to service majority of satellites, require stations at 28.5, 60 , 90
   - GEO satellites (station location not strong driver)

d) Shuttle is probably better than station for:
   - Servicing satellites at non-optimum times
   - Emergency resupply

e) Station offers unique capability independent of station or satellite location for:
   - Reconstitution via space-based launch
   - Shuttle crew rescue

In order to establish the number and location of satellites (1982 to 1992) a mission model was developed. Satellites were categorized by operational inclination and altitude and the number of satellites in each category is shown in Fig. 3-6. Many users place satellites in specific orbits for specific requirements; however, most civilian satellites are contained in two orbits (28.5 and 98 deg). As discussed earlier, scheduled maintenance and

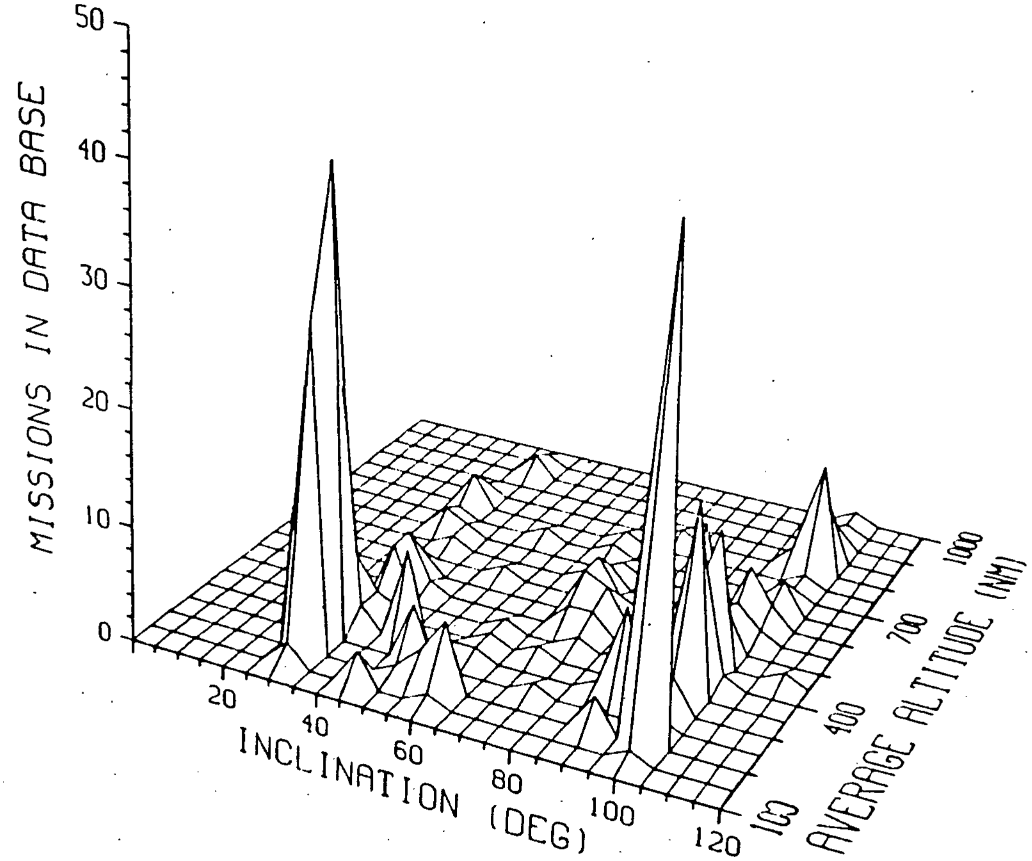

Fig. 3-6 Planned Mission Distribution

repair for satellites is done most efficiently at nodal coincidence; energy limitations require that a space station be at 28.5 deg and 90 to 98 deg if most civilian satellites are to be serviced from a space-based system.

This mission model containing 655 satellites is speculative because not all missions are approved or under way. The fact that most of satellites cluster in two inclinations indicates that many satellites can be serviced from a space-based system and that it makes sense to consider servicing as a primary function of a space station. An economic trade study comparing Space-Shuttle-based servicing with space station-based servicing shows a substantial cost advantage to the space station system even if only a few satellites are serviced in a given year.

A specific satellite servicing scenario (integrated Tactical Surveillance System-Based Radar) was analyzed as a case study to compare costs of station based and shuttle based systems. Details of the analysis are presented

in Attachment 1, Volume IV. Fig. 3-7 shows a comparison of shuttle and station based servicing costs which clearly indicates cost savings afforded with the station system. Attachment 1, Volume III includes details on both storable and cryogenic propellant OTVs as they are applied to applications such as the ITSS Space-Based Radar and shuttle rescue vehicles.

3.1.1.5 TECHNOLOGY

In the course of defining and identifying technologies that need to be further developed to support the feasibility of the evolutionary built-up Space Station, LMSC identified technology issues, TDMs, and technologies needing development. Technology issues were summarized in the following categories:

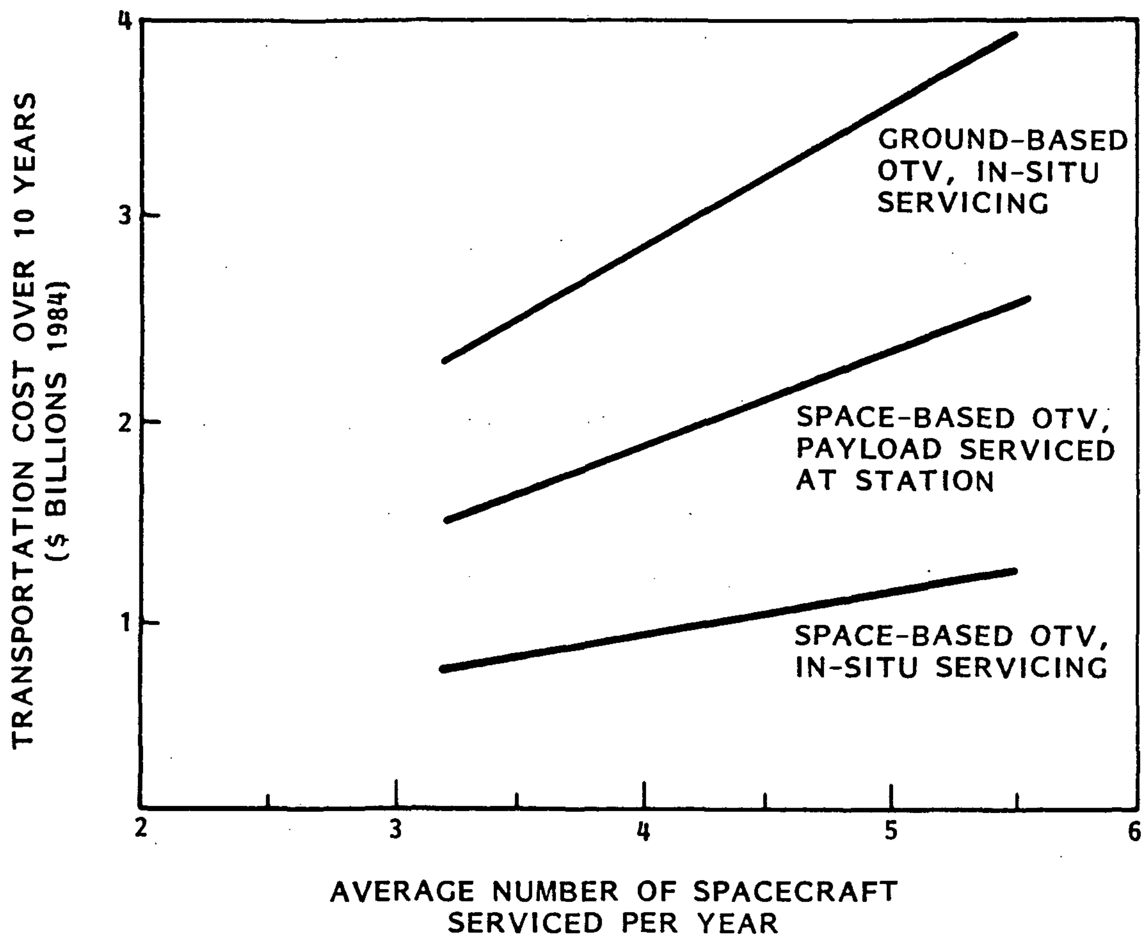

Fig. 3-7 Cost of Ground-Based versus Station-Based OTV Servicing

- Structures and Mechanisms
- Propulsion/Propellant Management
- Attitude Control and Stabilization
- Electrical Power
- Thermal Management
- Crew and Life Support
- Data Management
- Communication and Tracking
- Space Operations

Technologies were grouped on the basis of the above categories for which issues were identified and then analyzed as to their impact on Space Station concepts if such technologies were not available. The key factor was degraded capability of the station concepts in meeting functional requirements were the technologies not ready in time.

From the technologies identified and the alternate Space Station concepts identified in Section 3.2.1, a compatibility analysis was performed to define which concepts could be used to verify or develop the needed technologies to support the ultimate Space Station. Analysis results indicated that no single Space Station concept can be used to satisfy the verification or development of all of these needed technologies. It should be pointed out however that the initial Space Station can be developed without requiring most of these identified technologies but could not be part of the evolved system without provisions having been made to incorporate or accept the technology developments as they are made.

3.1.2 REQUIREMENTS FROM USER NEEDS

Evolution of user contacts resulted in a set of functions that must be performed by a manned space station on the station itself or in support of free flyers, platforms and other space station system elements such as OTVs. A summary of these functions follows:

1. Support for long duration payloads that need direct manned intervention
2. Support manned spacecraft that need periodic manned intervention (assembly, experiment changeout)
3. Support orbit staging, launch and recovery of free flyers
4. Test bed for development of sensors, techniques, support systems
5. Orbit placement and recovery of payloads
6. Logistics support interface with STS

Performance of these generalized functons requires that the space station provide for the following functional requirements.

1. Permanent manned habitation
2. Capability for long duration, low earth orbit operations
3. On orbit station assembly via STS interface
4. On orbit large structures assembly
5. On orbit logistics support via STS
6. Capability to deploy, retrieve and support payloads (periodic and continuous operations)
7. Data transfer/communication links with orbit-to-orbit and orbit-to-ground interfaces
8. Compatibility with STS infrastructure
9. Compatibility with DoD sytem infrastructure
10. Capability for growth (functions and operations)

Definition of more specific requirements was accomplished on a mission by mission basis through analysis of requirements imposed by each of the individual mission scenarios, Attachment 2, Volume I. These individual mission requirements are also provided in tabulated form in Attachment 2, Volume I.

Time phased mission requirements were established by imposing requirements throughout the 1990 to 2000 time frame in a manner consistent with current development status, likely funding levels and realistic STS launch capability. Fig. 3-8 evaluation and capability growth of the station OTV's an essential part of servicing, logistics, assembly and potential rescue, and crucial to the space station system intrastructure.

Implementation of the station to serve virtually all users satisfactorily in the initial stages leads to a simple 2-3 person crew size, with as little as 15 kW of power in a 28.5 degree inclined orbit.

3.1.3 FOREIGN CONTACTS

Lockheed executed data exchange agreements with four foreign companies interested in participating in a US space station program. They were:

SPAR	-	Toronto, Canada
GTS	-	London, England
MBB/ERNO	-	Bremen - Germany
DORNIER	-	Friedrichshafen - Germany

An engineer from SPAR worked directly with the Lockheed team in Sunnyvale, California for a period of two weeks. This effort was focused on application of the Remote Manipulating System to the station.

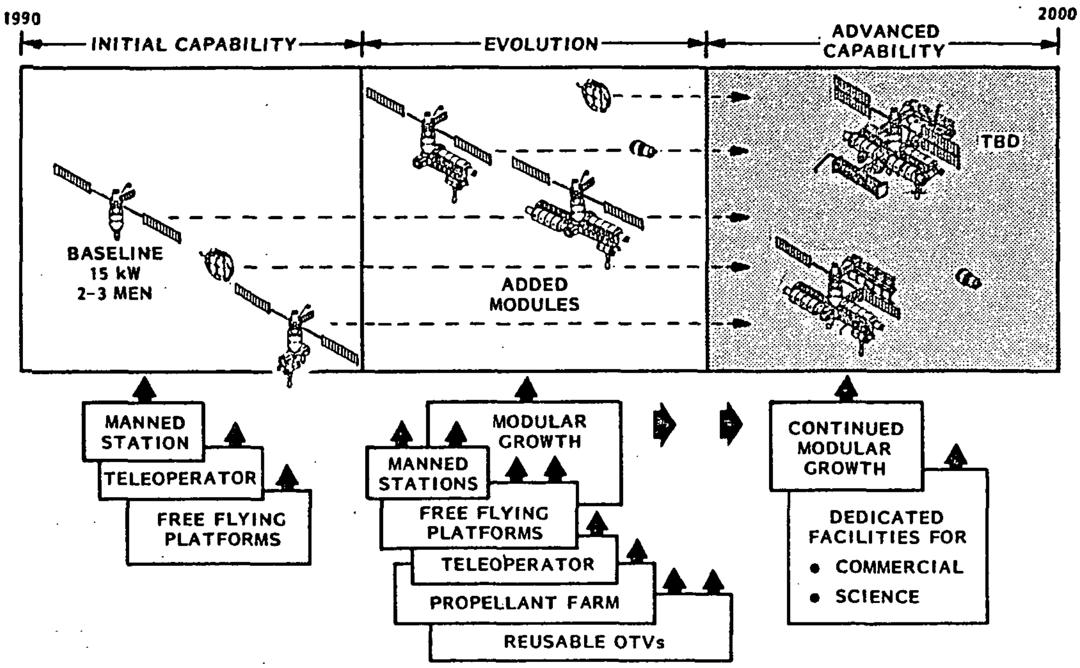

Fig. 3-8 Capability Growth

Personal visits by a Lockheed representative were made in Europe to the following companies and agencies.

ESA	-	Paris
ONERA	-	Paris
MAX PLANCK INSTITUTE	-	Munchen
MBB/ERNO	-	Munchen and Bremen
DORNIER	-	Friedrichshafen
MBB/ERNO	-	Bremen
DFVLR	-	Koln
FOKKER	-	Schiphol
GTS	-	London
TNO	-	Delft
ESTEC	-	Noordwyk

Through these visits it became clear that there was universal enthusiasm for participating in the space station development. The European expressed a strong desire to have a significant role in the development, such as responsibility for a complete subsystem, rather than a partial one. Also noted was the fact that the ESA space station study findings were consistent with our study findings.

3.2 MISSION IMPLEMENTATION CONCEPTS (TASK 2)

This task identified Space Station System Concepts in terms of functional attributes, evaluated and defined system architectural and configuration concepts, selected a reference configuration and defined evolutionary growth steps to implement the system. The overall task was directed toward development of a space station compatible with the overall space station system infrastructure illustrated in Fig. 3-9.

3.2.1 APPROACH AND MISSION SCENARIO ANALYSIS

Fifteen mission description scenarios developed from results of user surveys and evaluation of projected NASA and DoD mission models in Task 1 of this study were developed and are included in Attachment 2, Volume I. These scenarios were representative of the range of missions in the science, applications, commercial, U.S. national security, and space operation categories anticipated for the 1900 to 2000 era. A typical example of an architectural concept for a specific scenario is illustrated in Figure 3-10.

Each scenario was analyzed to develop functional sequences and to identify functional support requirements. Functions were grouped in significant subelements to define a system architecture and to identify major interfaces. From the defined functions and interfaces, the role and attributes of the space station are defined to implement each mission. A compatibility analysis was performed to define alternative system concepts to implement the fifteen mission scenarios.

Missions were grouped on a basis of commonality of orbit characteristics, functional requirements, and unique national security needs. Analysis results indicated that no single space station concept could satisfy all the missions. Five system concepts were selected to implement the mission grouping as follows:

1. Concept A is a basic space station with attached enclosed laboratory configuration in a 57 deg inclination orbit and will accommodate those missions to perform space environment, ground and ocean earth observations.

2. Concept B is a basic space station with attached enclosed laboratory configuration in a 28.5 deg inclination orbit and will accommodate those missions to perform life science and materials processing investigations.

3. Concept C is a basic space station supporting detached free-flyer satellites in a 28.5 deg inclination orbit and will accommodate automated observation facilities for celestial and meteorological investigations and a man tended automated materials production facility.

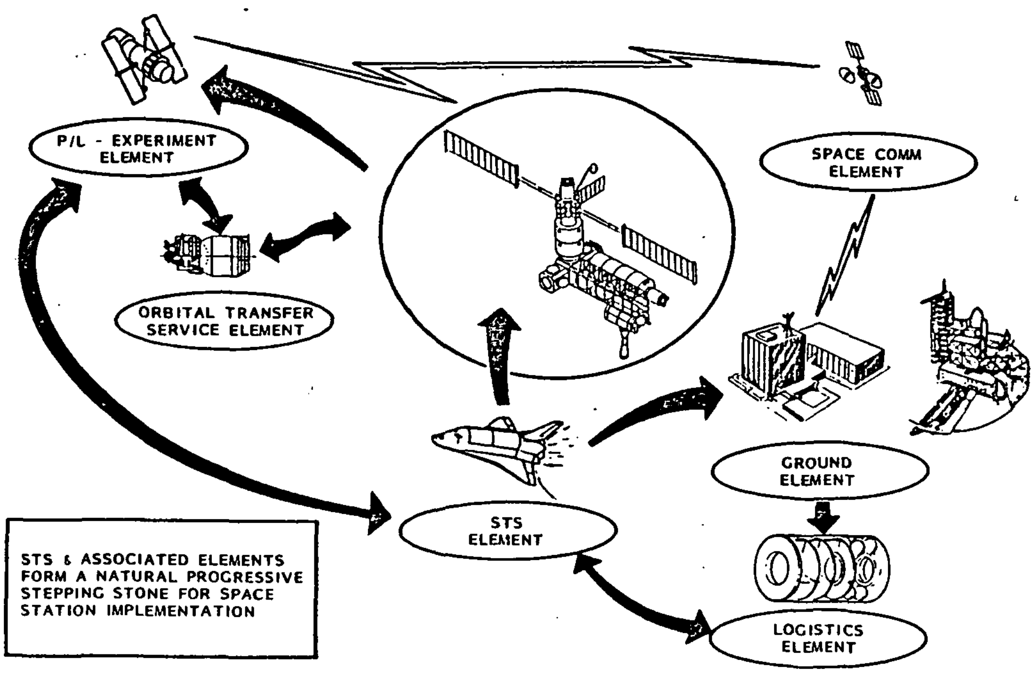

Fig. 3-9 Space Station System Infrastructure

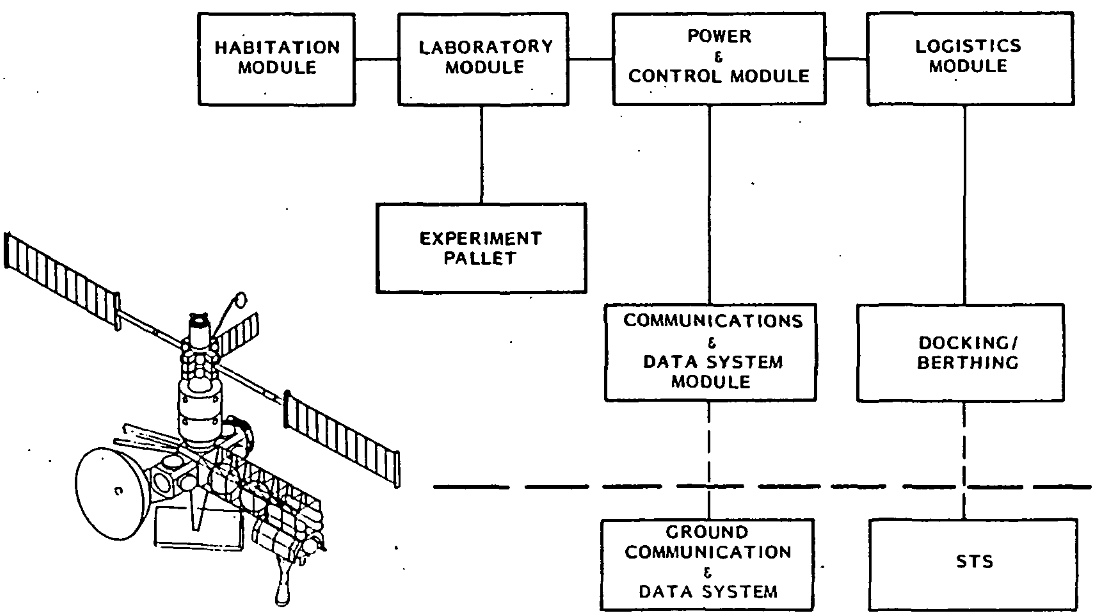

Fig. 3-10 Oceanography Observatory Development Lab. Architectural Concept

4. Concept D is a basic space station with attached facilities for performing maintenance/servicing of satellites and structural assembly and on orbit launch of large structures satellites.

5. Concept E are space station supported unique applications for U.S. National Security and will include an attached enclosed laboratory for Space Objects identification and a detached autonomous orbiting command post.

3.2.2 MISSION OPERATIONS AND ARCHITECTURAL ANALYSES

One of the most important pre-curser efforts needed to initiate architectural design was the definition of the basic station mission operations. Thus, effort was undertaken to identify the range of operations/functions which could be logically allocated to the station in support of the basic mission needs, logistics, ground interaction, and communications. This effort resulted in some 12 categories (with nearly 200 identified sub-operations) being established for inclusion of these operations/functions. These categories were:

1. Station assembly and activation
2. Station indigenous operations
3. Rescue and emergency support
4. Space logistics (including ground)
5. Communication and data system operations
6. Flight operations support
7. Mission support
8. Station based transport system operations
9. Stage assembly and checkout
10. Servicing and maintenance - spacecraft
11. Construction and assembly
12. Orbiter support

This effort provided substantial aid and insight to the configuration development activity, particularly, as a means of identifying functions that had to be incorporated into both general and special station architectural capability. As the design effort matured, the detailed operations list ultimately became a checklist of functions which were then cross correlated to station design capabilities.

Upon completion of the mission scenario development effort, activity was initiated on the identification of the operations and associated functions relative to the basic mission study elements which were:

- Science
- Applications

- Commercial
- US National Security
- Space Operations
- Technology Demonstration

From the scenarios, a set of 23 basic operational function categories were identified and within this composite, over 280 subcategory architectural influencing factors were derived. Each factor was then examined and rated on a low, medium, and high basis. Examination of the multitude of ratings revealed that those factors exhibiting a medium to high rating score should be considered architectural impacts. Accordingly, 104 factors, approximately 40 percent, were then incorporated into other design criteria and used as a basis for subsequent design and layout of the candidate station configurations.

This aforementioned activity logically led to the conduct of numerous analyses and trade studies in support of the subsequent architectural configuration layout effort. These analyses and trade presented in Volume IV, Task 2 are categorized as follows:

- Habitability
- Habitat layout
  - crew living modules
  - exper/lab/ops modules
- Sleep compartments/approaches
- Multi-purpose vehicle
- Plume impact
- Docking/berthing
- RMS/crane
- Partial gravity/tethering
- Stay-out envelopes
- Basic hardware elements
- Development paths

As a result of the extensive analysis and evaluation effort, a specific set of architectural drivers has been identified for the station. These drivers include operational, physical, dynamic, procedural, environmental, and programatic. Each driver was defined in sufficient detail so as to provide an impact characterization factor(s) for use in the architectural definition process.

Of all areas considered, those factors associated with programmatics have been the most difficult to identify and/or define. In particular, those factors associated with cost have been most difficult to forecast for the NASA out-year schedules. Similarly, the downstream mission needs as yet not fully defined also promote concern relative to comprehensibility with respect to levels and credibility of depth. Evolution of the station is based on a myriad of parameters, issues and current unknowns including cost;

nonetheless, bogie ceilings can be established and used as a basis of departure. Thus, in concert with the operational, physical, dynamic, procedural and environmental drivers, cost was used as a major driving element in the overall assessment of impact factors.

These factors were provided in summary form to the design team for incorporation as criteria guides used in the architectural definition process. Similarly, as the design progressed, these criteria were also used with the evolution rationale to aid in the station build-up sequence effort reported upon in subsequent charts.

3.2.3 EVOLUTION AND CONFIGURATION

An overall rationale for station evolution was developed and used to influence the development of the major station concept alternatives. Alternative configuration concepts were evaluated and a reference space station concept was selected. Space station evaluation may take alternative paths with time through implementation of different modules, subsystems and/or capabilities. Fig. 3-11 illustrates various alternatives as the station is evolved.

3.2.3.1 RATIONALE FOR STATION EVOLUTION

Complete and fully justified station evolution rationale was beyond the scope, and current state of mission/user need definition at this time. Nonetheless, several important and pivotal issues could be identified which bear upon the evolution consideration. Six basic categories were defined wherein the rationale has been allocated and are:

- Programmatics
- Expand capabilities
- Operational enhancement
- User needs
- Research and Development
- Demonstrations/Technology

Nearly 60 discrete rationale items have been identified and many have sub-factors which further expand the list. Subsequent future studies could logically be addressed as to the substantive impact of each and the associated relative merit. Of all the rationale presented, that category associated with the sub-category (under Programmatics) entitled Intangibles proves to be the most difficult to deal with in terms of methods of substantiation, dollar or instrinsic value, benefit, and importance. Certainly, NASA budget forecasts are difficult to portray at this time, thus, the budgetary picture is also elusive.

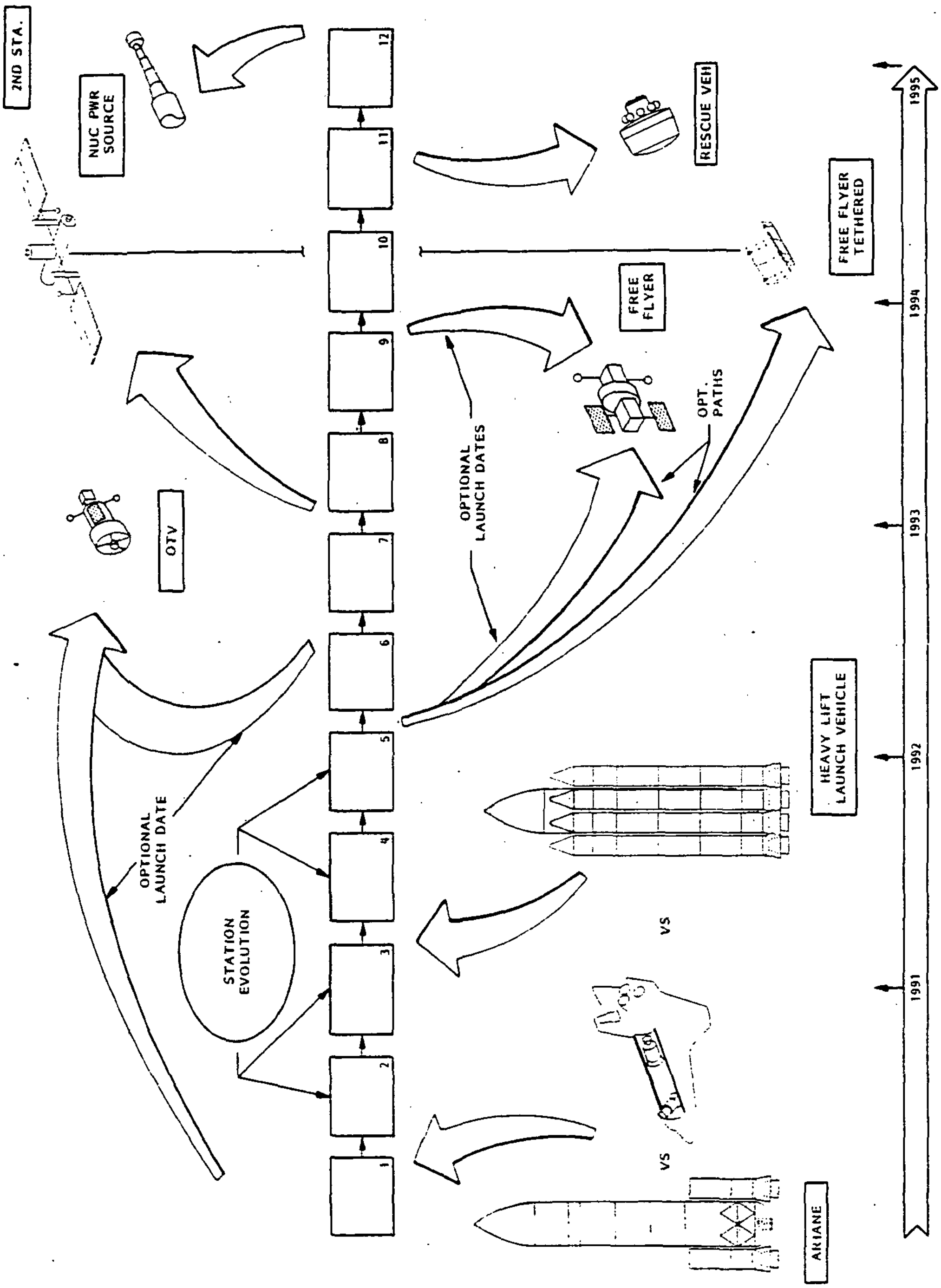

Fig. 3-11 Station Evolution Options

The general composite of rationale for evolution were submitted to and applied in the generic studies of conceptual station architectural definition and build-up. As the concepts were narrowed, the rationale became more important, particularly as to the evolutionary stepped build-up sequence and the associated costing implications.

3.2.3.2 CONFIGURATION

To satisfy the many different requirements of the five mission categories; Science, Applications, Commercial, U.S. National Security and Space Operations a variety of configurations have been examined and a reference station selected for use in a cost analysis study.

The National Security requirements pose a separate problem for any station where non-military personnel and operations are present, therefore it was decided to place the effort on national security as a separate entity as a Space Based Command Post which is discussed in other volumes of this report. However, it is recommended that much sensor development work, with man as a decisive evaluator/decision-maker could be a major function of the basic space station, therefore a sensor development laboratory workshop is inherent in all configurations.

We analyzed 15 classes of potential space missions within the categories of Science, Applications, Commercial, U.S. National Security and Operations. From these operations analyses space station system functions and architectural groupings were identified. On a basis of functional commonality and operations compatibility, we identified eight (and then synthesized to five) top level system concepts and the system functional interfaces. These essentially define the space station systems to accommodate the mission sets that were evaluated.

Initially a top-level evaluation was performed of the alternate system concepts to identify the major influences on the station architecture. Since our emphasis during this study has been to concentrate on the conceptual framework for a space station rather than on detail design, we set aside most of the subsystem influencing factors as candidates for future studies. We did consider those subsystem drivers which will influence overall configuration arrangement and layout, such as habitation sizing and work area arrangements for personnel and for performing station satellite servicing and construction/assembly operations.

Architectural options were explored from a standpoint of configuration, layout arrangement, operations activities, crew support and safety. Station performance capability was evaluated based on criteria such as growth, safety, logistics support needs, servicing and maintenance needs, crew interaction needs and operational compatibility with space infrastructure including space transportation elements and communication networks.

Results of the station suitability assessment were used in supporting configuration development analysis and cost effectiveness analysis to identify candidate space station configurations.

A substantial listing and numerous design layouts were prepared of the many hardware elements which in one way or another influence the architectural space station configuration. Envelope drawings and system mass properties of most of these have been entered into our Cadam data base and were used extensively during this study. Data sheets detailing design functions, performance, field of view (FOV), envelope geometry, weight, etc., have also been prepared to simplify and provide a common data base, in the configuration study process. Much of the data was obtained, and is referenced to, existing NASA and industry reports.

Eight major configuration alternatives for the space station were synthesized from over 50 differing concepts. These major configurations were then examined relative to the principal system design drivers as listed below:

- Control, stability, pointing
- Orientation; earth fixed/inertial/combinations
- Safety
- Crew size
- Docking capability
- Payload accomodation and FOV
- Antennae FOV
- Mass properties, M of I plus CG excursions
- Power supply type plus orientation
- RCS plume inpingement/contamination
- OTV + visiting spacecraft operations
- Servicing
- Modularity, evolutionary
- Thermal control
- Launch configuration
- EVA

The shuttle was always used (in this study) as the basic transportation vehicle with a capability of 63,000 lb to 150 NM orbit at 28.5 deg inclination, although this is conservative as some projections suggest that by 1985, with all SRB, ET plus shuttle improvements included, the capability could be as high as 80,000 lb. The probability of funding being available for the heavy lift shuttle configurations is considered low at this time. Therefore, heavy lift launch vehicles were not considered in this study.

In addition to the command post concept, the military space station could be developed in the same way as the LMSC reference station; or it could be a series of free flyers operating around a basic core command system. There are numerous possibilities. The eight configuration alternatives are presented briefly in the following paragraphs.

The reference station has been designed to permit evolution both in form and functional capability. A basic capability is established in 1990 with the single shuttle launch of a three man habitation module combined with a permanently attached electrical power module, and a retractable sensor experiment test bed. This initial station is maintained, with shuttle resupply visits, for a full 12 months during which time all of the subsystems, controls, communication, power, thermal control, etc., would be thoroughtly flight tested prior to delivery of the remaining station elements.

The station build up is phased over a six year period and averages two shuttle launches per year for transport of station elements to orbit. Incremental capability is added in successive launches such that the station is always operational from the first launch and is flexible enough to accommodate changes in launch make-up and mission requirements. It is assumed that some resupply of the station (personnel and supplies) can be accomplished during the placement launches. In addition up to two resupply visits will be required each year to maintain the station.

The addition to final capability configuration is accomplished in 1996 by addition of an enclosed research module laboratory and a specialized materials processing laboratory. At this time (1996) the station is effectively functioning as an operational space transportation node and full capability research facility.

The need for an orbital transport vehicle is highly viable, however, the RDT&E date for station application support has not been formally established (e.g., 1990 to 1993 time frame). Similarly, the numbers, types, and capabilities of the free flyers anticipated for the 1990 to 2000 time frame are somewhat soft at this time, however, every indication tends to support the potential of their availability beginning late 1991 and continuing thereafter. The potential application of certain of these free flyers to more simplified payloads exists relative to the possibility of tethering these from the station itself.

A second (or third) station potential exists and could be implemented as early as 1994/5. In association with the station(s) will be the need for a rescue vehicle (with multi-purpose applications) which could come on line in the mid-1990's. A nuclear power source may be required for the Command Post Module (DoD mission/program), thus it may launched as early as 1995. This power source may also have application to station tethered uses for supplemental power.

Tent and triangular concept layouts are loosely based on some JSC ideas whereby the solar arrays are not always sun oriented; but the concepts aim for very high stiffness thereby simplifying control and stability; attitude being maintained by large CMG's located at each corner. A concept layout was made of the converted external tank both as a hangar and for experiment areas, habitation, power, and control module support. The 'Stonehenge' arrangement concept has four interconnected habitable modules with areas inside and out for spacecraft and assembly operations.

The rigid raft concept prepared has major working/assembly areas on a grid type structure above and/or below the main pressurized habitation and laboratory modules.

A typical 'tuna can' (stacked cylinders) approach was developed as a rigid structure to permit access to a multi-experiment pallet.

A variation of the MSFC vertical assembly complex was also prepared and the eighth concept prepared is the LMSC reference station used in the cost analysis of this study.

The possibility of developing the tethered satellite concept has been briefly addressed and some interesting concepts have evolved and are discussed in some detail,

primarily in the orbit mechanics field, Attachment 1, Volume III, Section 1.5. Sketches were prepared illustrating typical configuratins for true tether concepts using vertical or horizontal complex's including close-in tether system whereby the modules requiring physical isolation from the main space station are suspended in special devices but remain close-hauled to it.

Selection of a final preferred configuraton was not attempted since its requirements will not be firmly known for some time; however, to help make the costing task more simple, a reference SS has been developed.

A wide variety of configurations have been examined (over 50 concept layouts were prepared). Since a prebuilt (on earth) pressure vessel is needed for habitation and laboratory use, a longitudinal cylinder approximately 14 ft in diameter and 45 ft long, capable of being launched by the shuttle, makes sense as the primary modular building block around which various special-purpose modules and structures for experiments and equipment can be attached. However, since basic structure represents only a small part of the system cost care must be used in evaluating designs which are primarily configured to use existing hardware.

If earth transportation via C5 aircraft becomes a requirement (attractive for military SS elements), the cylinder diameter would be reduced to approximately 12.5 ft. Use of a cargo carrier mounted on the 747 would eliminate this size constraint.

Arranging the cylinders vertically gives a fragmented interior arrangement and provides less opportunity for earth or outward (to space) viewing experiments. Therefore, a horizontal arrangement was selected.

Should a very large-diameter module become a viable candidate, then the aft cargo compartment of the external tank, or a section within the external tank itself, could be used.

It is obvious that NASA encourages an open-minded approach to design until more firm and detailed requirements are established.

Primarily for the purposes of evaluation (growth), mission suitability needs assessment and costing analyses, a reference space station layout has been prepared. The principal features associated with this concept are:

Modular Approach	Early initial capability; growth provisions
Experiment Integration	Provide work areas and platforms, internal and external
Crew Size	Three initially, growing to six
Power	Solar array 13 kW growing to 26 kW
Safety	Two independent living cells and rescue capability
Type of Control	Earth oriented, active RCS thrusters
Habitation & Lab Module Size	14 ft diam x 40 ft long
Servicing	Provide for OTV, visiting spacecraft, TMS, etc.
Communications	Primarily provide FOV for dish to ground and TDRSS (there will be many other antennae).
Resupply	Crew and consumables every 90 days
EVA	Provide volume and equipment to support EVA

A determined effort was made to make the station as compact as possible, not only to provide good FOV for solar arrays, radiators, payloads (e.g., experiments) and antennae but to simplify attitude control + CG + MOI excursions, and also to provide maximum availability and ease of docking during external operations.

3.2.4 REFERENCE SPACE STATION EVOLUTION

An evolutionary space station to be initiated in 1990 has been conceptualized, mainly for purposes of costing and funding analysis. The evolution is illustrated in Fig. 3-12.

Each step towards the build-up of an advanced space station was based on user requirements when available, a set of scenarios of which some were endorsed covering the five mission categories, and engineering judgements of needs that may surface during the station growth.

Although these steps were logically developed, they are obviously subject to change as more requirements become known, specifically in the national security and commercial areas. However, the main reason for this evolution was to obtain a reference cost base which could be used as a gage for total expenditure requirements and would form a base line cost for future requirements input and change.

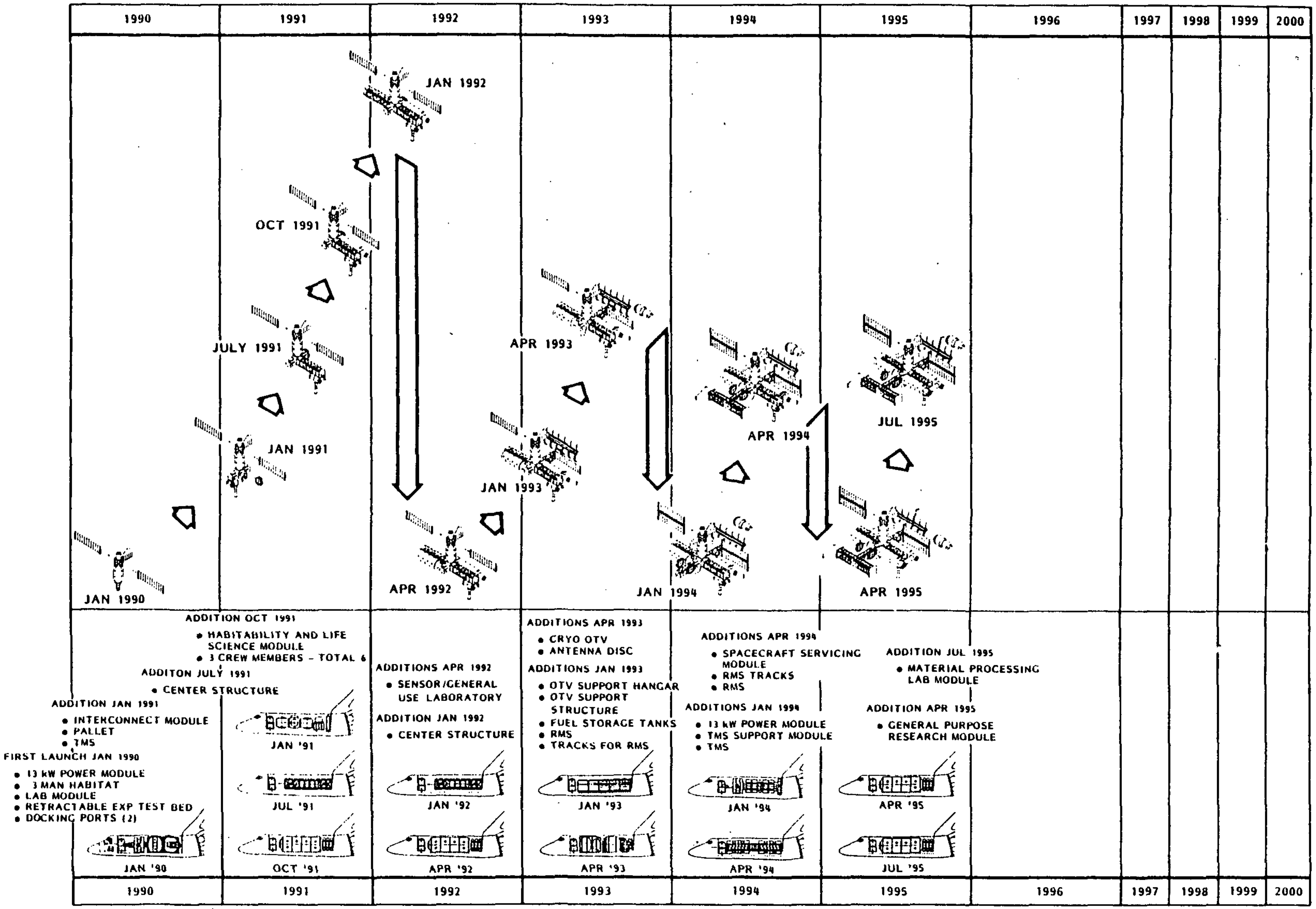

Fig. 3-12 Space Station Evolution

Details of design were kept to a minimum consistent with requirements for cost analyses. Details of this evolution are presented in Attachment 2, Volume I.

3.3 COST AND PROGRAMATIC ANALYSIS

The purpose of Task 3 was to define the resource outlays and the potential returns of a Space Station program. This effort was split into two subtasks, i.e., Benefits Analysis (3.1) and Cost, Schedule and Funding Analysis (3.2).

3.3.1 BENEFITS ANALYSIS

The analysis of Space Station benefits considered two general classes of payoffs that would result from development of a Space Station. These are: 1) quantifiable benefits in which the advantages of a Space station over its alternatives can be reduced to cost savings at equal mission capability, and 2) nonquantifiable (qualitative) benefits.

Analysis of quantifiable benefits was focused on microeconomic trends as defined by means of case studies that involve realistic mission scenarios. The area of study was Space Station enchancement of the national Space Transporation System, and in particular enhancement of the Orbital Transfer Vehicle (OTV). In just one case study of scheduled maintenance, savings of up to $2.6 billion (1982), or $3.0 billion (1984), were attributed to the presence of a Space Station as a depot for space-based OTVs. These savings were identified in a mission application that involved scheduled servicing of a large constellation of observation satellites. The primary mechanism for savings was efficient use of the STS (shared versus dedicated Shuttle flights, tailored OTV propellant loadings). Most importantly, these savings were not tied to the feasibility of propellant scavenging from the External Task. Such scavenging, if feasible, would only magnify the savings attainable with a Space Station-based OTV.

The nonquantified, or qualitative, benefits of a Space Station occur in areas that relate to the well-being of some populace. Typical areas include:

- Benefits from the critical mass of a Space Station program, e.g., large-scale space industrialization; technological and industrial continuity in times of transition; and significant international participation.

- Benefits to national security from the continuing presence of man, expecially with regard to survivable command authority.

- Benefits in STS crew safety due to presence of a 'safe haven' at the Space Station.

The case-study method is the most promising technique for future assessment of Space Station benefits. It provides mission scenarios based on real operational needs; it documents design and mission definition; and it provides a traceable link from costs to benefits.

3.3.2 COST, SCHEDULE AND FUNDING ANALYSIS

Emphasis in the cost and schedule analysis was on identifying cost drivers, funding patterns, and evolutionary trends. The cost estimates cover development, production, operation and deployment of the reference Lockheed Space Station evolutionary architecture. The estimates exclude costs for development and support of Station payload costs. Likewise, costs for acquisition and operation of the OTV and Teleoperator Maneuvering System were omitted from the cost tabulations even though they were used in the benefits analysis.

The total estimated cost of the seven-step Lockheed evolutionary space station architecture is $9.86 billion in constant - 1984 dollars. Step 1 deploys a Station that represents an initial operational capability at a cost of $2.8 billion. Steps 2 through 4 augment this capability in increments for an added cost of $2.8 billion ($5.6 billion cumulative). Step 5 adds OTV servicing capability for an added cost of $1.4 billion ($7.0 billion cumulative). Step 6 adds spacecraft servicing capability at an added cost of $1.3 billion ($8.3 billion cumulative). Step 7 completes the configuration and adds materials processing capability for an added $1.6 billion ($9.9 billion cumulative). Figure 3-13 illlstrates the program projected funding profile.

The time-phased buildup of Space Station expenditures depends on the deployment dates for each evolutionary segment. In the reference Lockheed scenario first launch of Step 1 occurs in January 1990 and the last launch of Step 7 in July of 1995. With this scenario, peak annual funding of just under $1.5 billion occurs in the sixth and seventh years after program go-ahead. However, by deferring introduction of the evolutionary segments, this peak can be held to under $1.0 billion.

YEARLY EXPENDITURE SUMMARY

COSTS IN DOLLARS — 1 JAN 84 UNITS

PERIOD ENDING	PER CENT COMPLETE	EXPENDITURES FOR PERIOD TOTAL	EXPENDITURES FOR PERIOD %	CUMULATIVE EXPENDITURES TOTAL	CUMULATIVE EXPENDITURES %
DEC 84	0.0	1.0	0.0	1.0	0.0
DEC 85	1.0	102.7	1.0	103.7	1.0
DEC 86	4.5	369.6	3.5	473.3	4.5
DEC 87	10.3	605.6	5.8	1078.9	10.3
DEC 88	17.6	752.9	7.2	1831.7	17.6
DEC 89	27.1	999.8	9.6	2831.5	27.1
DEC 90	41.1	1455.7	14.0	4287.3	41.1
DEC 91	54.9	1445.9	13.9	5733.2	54.9
DEC 92	66.7	1226.2	11.8	6959.4	66.7
DEC 93	78.1	1187.8	11.4	8147.2	78.1
DEC 94	87.8	1015.4	9.7	9162.6	87.8
DEC 95	94.4	691.7	6.6	9854.2	94.4
DEC 96	100.0	580.2	5.6	10434.4	100.0

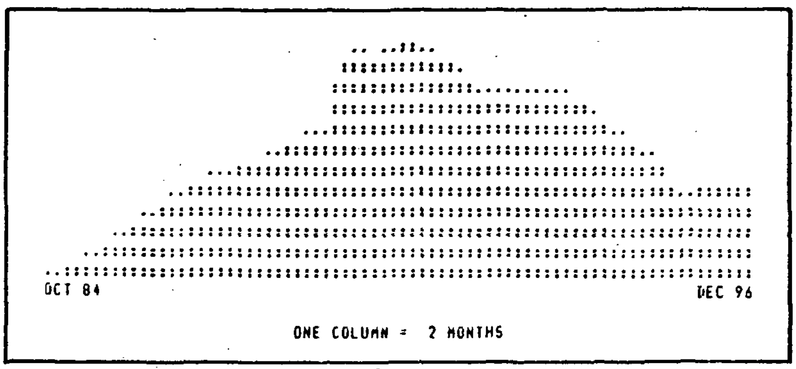

Fig. 3-13 Program Funding Profile

Acquisition cost drivers for the Space Station include test philosophy (protoflight versus one or more dedicated test vehicles); relative state of the art; and inheritance (for both hardware and software). Operational cost drivers include STS resupply intervals and STS price per flight.

Section 4
STUDY CONLCUSIONS AND RECOMMENDATIONS

Conclusions drawn from the conduct of this study, potential user contacts and our philosophical outlook on the need of an American space station follow.

4.1 STUDY PERFORMANCE

Our approach to the conduct of this study, as shown in the user alignment plan proved to be a successful method, and we would not change this approach for studies of this type.

A high number of personal contacts were made during the study period. This is the only way to obtain a credible consensus in the mission categories contacted. Repeat contacts have to be made and in some cases these can give surprising and positive results.

In the area of U.S. National Security an overall attitude of "no need" for a space station changing to one of a specific need was observed at at least one operational command after three or four visits.

The commercial area presents a rather dim picture at present. Very few solid endorsees for commercial space ventures have been found. Substantial interest exists but it is interwoven with uncertainty, based both on the unknown quantity "space", and on the economic situation. The fact that Space Station is at least 8-10 years away did not help. Although the return on investment could be phenomenal for successful ventures, the initial investment and the risks are high. Furthermore, a surprising lack of knowledge about the space environment exists in the commercial sector, calling for improved education and measures to show what can be accomplished in space.

To summarize, our approach of multiple visits changed some initially negative viewpoints. Continuation of contacts, particularly in the commercial sector, is needed.

4.2 LOCKHEED ASSESSMENT

The following statements and conclusions summarize our assessment of present space station status:

1. Personal contact-user alignment plan successful, should be continued to prevent momentum loss

2. Foreign interests eager to participate; cooperative approach beneficial

3. Space station will advance science and application now constrained by STS limitations
   - Longer term
   - Lower cost

4. USA must accelerate high technology to withstand foreign competition

5. OTV's essential to system operation
   - Existing OTVs support some missions
   - Advanced OTVs will expand capability for remote operations

6. Initial station characterized by simplicity
   - 28.5 deg Inclination
   - 15 kW Power
   - Two or three Persons
   - Single shuttle launch

7. Space station provides powerful capability for space-based operations

8. Understanding of orbital mechanics constraints is essential for proper mission planning and support.

9. Station is better than shuttle for supporting scheduled servicing, maintenance, and resupply of:
   - Payloads and satellites in space station very close proximity orbits
   - Satellites in nearby inclinations at nodal coincidence; to service majority of satellites, require stations at 28.5 deg, 60 deg, 90 deg
   - GEO satellites (station location not strong driver)

10. Shuttle is probably better than station for:

    - Servicing satellites at non-optimum times
    - Emergency resupply

11. Station offers unique capability independent of station or satellite location for:

    - Reconstitution via space-based launch
    - Shuttle crew rescue

12. A low cost launch vehicle will be required before large scale military and commercial missions will be economically feasible.

Lockheed Missiles & Space Company, Inc.